Introduction and recent developments in $\gamma\gamma$,γe colliders

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Abstract.
High energy photon colliders ($\gamma\gamma$, γe) based on backward Compton scattering of laser light is a very natural addition to e^+e^- linear colliders. In this report we consider mainly this option for the TESLA project. Recent study has shown that the horizontal emittance in the TESLA damping ring can be further decreased by a factor of four. In this case the $\gamma\gamma$ luminosity luminosity in the high energy part of spectrum can reach 0.3–0.5 $L_{e^+e^-}$. Typical cross sections of interesting processes in $\gamma\gamma$ collisions are higher than those in e^+e^-collisions by about one order of magnitude, so the number of events in $\gamma\gamma$ collisions will be more that in e^+e^- collisions. The key new element in photon colliders is a very powerful laser system. The most straightforward solution is “an optical storage ring (optical trap)” with diode pumped laser injector which is today technically feasible. This paper briefly review the status of a photon collider based at TESLA, its possible parameters.

I INTRODUCTION

Over the last decade, several laboratories in the world have been working on linear e^+e^- collider projects with an energy from several hundreds GeV up to several TeV. Beside e^+e^- collisions, linear colliders can “convert” electrons to high energy photons using the Compton backscattering of laser light, thus obtaining $\gamma\gamma$ and γe collisions with energies and luminosities close to those in e^+e^- collisions [1,2]. Recently the International Workshop on High Energy Photon Colliders has been held at DESY. There are very good news, which I will discuss below.

The basic scheme of a photon collider is shown in Fig. 1.

The maximum energy of the scattered photons (in direction of electrons) is [1]

$$\omega_m = \frac{x}{x+1}E_0; \quad x = \frac{4E_0\omega_0\cos^2\alpha/2}{m^2c^4} \simeq 15.3\left[\frac{E_0}{\mathrm{TeV}}\right]\left[\frac{\omega_0}{eV}\right], \tag{1}$$

where E_0 is the electron energy, ω_0 the energy of the laser photon, α is the angle between electron and laser beam (see, fig.1a). For example: E_0 =250 GeV, ω_0 =

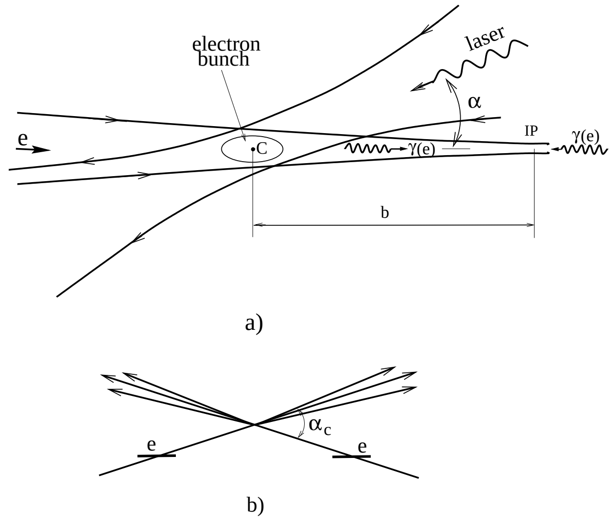

FIGURE 1. Scheme of $\gamma\gamma$, γe collider.

1.17 eV ($\lambda = 1.06$ μm) (Nd:Glass and other powerful solid state lasers) $\Rightarrow x = 4.5$ and $\omega/E_0 = 0.82$. For an introduction to photon colliders see refs [1,2].

Below I will discuss most important issues connected with a photon collider based on the TESLA [3]. The following essential topics are discussed: physics motivation, parameters of the photon collider at TESLA, lasers, optics.

II PHYSICS

In general, physics in e$^+$e$^-$ and $\gamma\gamma$, γe collisions is quite similar because the same particles can be produced. However, it is always better to study new phenomena in various reactions because they give complementary information. Some phenomena can best be studied at photon colliders due to better accuracy or larger accessible masses.

The second aspect important for physics motivation is the luminosity. Typical luminosity distribution in $\gamma\gamma$ and γe collisions has a high energy peak and some low energy part (see the next section). This peak has a width at half maximum of about 15% (in $\gamma\gamma$ collision) and photons here can have a high degree of polarization. In the next section we will see that in the current TESLA designs the $\gamma\gamma$ luminosity in the high energy peak can be up to 30-40% of the e$^+$e$^-$ luminosity at the same beam energy.

Higgs boson

The present Standard Model (SM) assumes existence of a very unique particle, the Higgs boson. It has not been found yet, but from existing experimental information it follows that, if it exists, its mass is higher then 112 GeV (LEP200) and is below 200 GeV, i.e. lays in the region of the next linear colliders. In the simplest extensions to the SM the Higgs sector consists of five physics states: h^0, H^0, A^0 and $H^{\pm}$. All these particles can be studied at photon colliders and some characteristics can be measured better than in e$^+$e$^-$ collisions.

The process $\gamma\gamma \to H$ goes via the loop with heavy virtual charged particles and its cross section is very sensitive to the contribution of particles with masses far beyond the energies covered by present and planned accelerators. For the integrated luminosity 50 fb^{-1} (in the peak) the number of produced Higgs will be 50–150 thousands (depending on the mass). As a result, one can measure the $\Gamma_{\gamma\gamma}(H)$ width at photon colliders with an accuracy better than 2-3% [5]. This is sufficient for distinguishing between Higgs models [6].

Moreover, in the models with several neutral Higgs bosons, heavy H^0 and A^0 bosons have almost equal masses and at certain parameters in the theory are produced in e^+e^- collisions only in associated production $e^+e^- \to HA$, while in $\gamma\gamma$ collision they can be produced singly with sufficiently high cross section. Correspondingly, in $\gamma\gamma$ collisions one can produce Higgs bosons with about 1.5 times higher masses.

Charge pair production

The second example is the charged pair production. Cross sections for the production of charged scalar, lepton, WW pairs in $\gamma\gamma$ collisions are larger than those in e^+e^- collisions by a factor of approximately 5–20. The corresponding graphs can be found elsewhere [2,4].

Note, that in e^+e^- collisions two charged pairs are produced both via annihilation diagram with virtual γ, Z and also via exchange diagrams where some new particles can give contributions, while in $\gamma\gamma$ collisions it is pure a QED process which allows the charge of produced particles to be measured unambiguously.

Accessible masses

In γe collisions, charged particle with a mass higher than that in e^+e^- collisions can be produced (a heavy charged particle plus a light neutral); for example, supersymmetric charged particle plus neutralino or new W boson and neutrino. Also, $\gamma\gamma$ collisions provide higher accessible masses for particles which are produced as a single resonance in $\gamma\gamma$ collisions (such as neutral Higgs bosons).

Search for anomalous interactions

Precise measurement of cross sections allow the observation of effects of anomalous interactions. The process $\gamma\gamma \to$ WW has large cross section (about 80 pb) and it is one of most sensitive processes for a search for a new physics. The vertex γWW can be studied much better than in e^+e^- collisions because in the latter case the cross section is much smaller and this vertex gives only 10% contribution to the total cross section. The two factors together give about 40 times difference in the cross sections. Besides that, in $\gamma\gamma$ collisions the $\gamma\gamma WW$ vertex can be studied.

Quantum gravity effects with Extra Dimensions

This new theory suggests a possible explanation of why gravitation forces are so weak in comparison with electroweak forces. It is suggested that the gravitation constant is equal to the electroweak but in a space with extra dimensions. It can be tested at photon colliders and a two times higher mass scale than in e^+e^- collisions can be reached [8].

Many other examples can be found in proceedings of GG2000 Workshop [7].

III POSSIBLE LUMINOSITIES OF $\gamma\gamma$,γe COLLISIONS AT TESLA

As it is well known in e^+e^- collisions the luminosity is restricted by beamstrahlung and beam instabilities. Due to the first effect the beams should be very flat. In $\gamma\gamma$ collisions these effects are absent, therefore one can use beams with much smaller cross section. At present TESLA beam parameters the $\gamma\gamma$ luminosity is determined only by the attainable geometric L_{ee} luminosity. So, the $\gamma\gamma$ luminosity depends on emittances of electron beams.

Specially for photon collider the TESLA group has studied the possibility of decreasing emittances at the TESLA damping ring. The conclusion is that the horizontal emittance can be reduced by a factor of 4 in comparison with the previous design.

The resulting parameters of the photon collider at TESLA for 2E=500 GeV and H(130) are presented in Table 1 [9]. It is assumed that electron beams have 85% longitudinal polarization and laser photons have 100% circular polarization and that $L \propto E$. The thickness of laser target is one collision length (so that $k^2 \approx 0.4$).

TABLE 1. Parameters of the $\gamma\gamma$ collider based on TESLA. Left column for 2E=500 GeV, next two columns for Higgs with M=130 GeV, two options.

	2E=500 $x = 4.6$	2E=200 $x = 1.8$	2E=158 $x = 4.6$
$N/10^{10}$	2	2	2
σ_z, mm	0.3	0.3	0.3
$f_{rep} \times n_b$, kHz	14.1	14.1	14.1
$\gamma\epsilon_{x/y}/10^{-6}$,m·rad	2.5/0.03	2.5/0.03	2.5/0.03
$\beta_{x/y}$,mm at IP	1.5/0.3	1.5/0.3	1.5/0.3
$\sigma_{x/y}$,nm	88/4.3	140/6.8	160/7.6
L_{ee}(geom), 10^{33}	120	48	38
$L_{\gamma\gamma}(z > 0.8 z_{m,\gamma\gamma})$, 10^{33}	11.5	3.5	3.6
$L_{\gamma e}(z > 0.8 z_{m,\gamma e})$, 10^{33}	9.7	3.1	2.7

For these luminosities the rate of production of the SM Higgs boson with M_H=130(160) GeV in $\gamma\gamma$ collisions is 0.9(3) of that in e^+e^- collisions at 2E = 500 GeV (both reactions, ZH and H$\nu\nu$).

Comparing the $\gamma\gamma$ luminosity with the e^+e^- luminosity ($L_{e^+e^-} = 3 \times 10^{34}$ cm^{-2}s^{-1} for $2E = 500$ GeV) we see that for the same energy

$$L_{\gamma\gamma}(z > 0.8 z_m) \sim 0.4 L_{e^+e^-}. \tag{2}$$

For example, the cross section for production of H^+H^- pairs in collisions of polarized photons is higher than that in e^+e^- collisions by a factor of 20 (not far from

the threshold); this means 8 times higher production rate for the luminosities given above. The relation (2) is valid only for the considered beam parameters. A more universal relation is (for $k^2 = 0.4$)

$$L\gamma\gamma(z > 0.8z_m) \sim 0.1L_{\mathrm{ee}}(geom). \tag{3}$$

Figures for the luminosity distribution in $\gamma\gamma$ and γe collisions can be found elsewhere [9].

IV LASERS, OPTICS

A key element of photon colliders is a powerful laser system which is used for e$\rightarrow\gamma$ conversion. Lasers with the required flash energies (several J) and pulse duration $\sim$ 1 ps already exist and are used in several laboratories. The main problem is the high repetition rate, about 10–15 kHz, with a pulse structure repeating the time structure of the electron bunches.

The most attractive and reliable solution at this moment is an "optical storage ring" with a diode pump laser injector. This new approach can be considered as a base-line solution for the TESLA photon collider [9]. This scheme with multiple use of each laser bunch is shown in fig. 2.

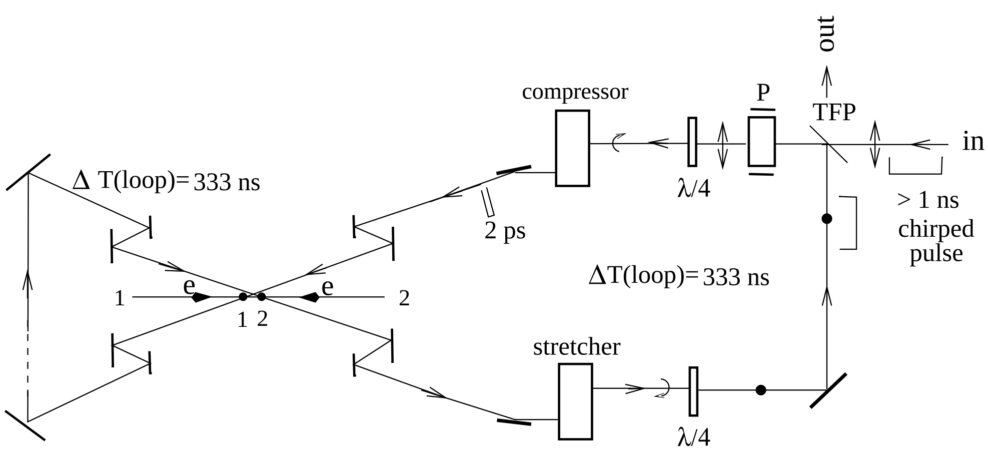

FIGURE 2. Optical storage ring for $e \rightarrow \gamma$ conversions. P is a Pockels cell, TFP is a thin film polarizer, thick dots and double arrows show the direction of polarization.

The laser pulses are send to the interaction region where they are trapped in an optical storage ring. This can be done using Pockels cells (P), thin film polarizers (TFP) and 1/4-wavelength plates ($\lambda/4$). Each bunch makes several (n) round trips (I assume n=10 for further example) and then is deleted from the ring. All these tricks can be done by switching one Pockels cell.

During one total loop each bunch is used for conversion twice. To avoid problems of non-linear effects (self-focusing) in optical elements, laser pulses which are compressed before collisions down to about 2 ps using grating pairs are then stretched

again up to previous length before passing through optical elements. Such system can be done in the best way only at the TESLA due to a large spacing between bunches and a long train.

A laser system required for a such optical storage ring with 10 round trips can consist of about 8 lasers of 0.9 kW average powereach. Due to the high average power the lasers should be based on diode pumping. Diodes have much higher efficiency than flash lamps and much more reliable. This technology is developed very actively for other application, such as inertial fusion. Present cost of diodes for such laser system is about 15 M$ (for 10-fold use of one laser bunch as described above) and it is expected that their cost will be further decreased several times. Such system can be done now: all technologies exist.

V CONCLUSION

The luminosity in $\gamma\gamma$ collisions (in the high energy peak) can reach about 40% of e^+e^- luminosity. Since cross sections in $\gamma\gamma$ collisions are typically higher by one order of magnitude than those in e^+e^- collisions and because of access to higher masses for some particles, the photon collider now has very serious physics motivation.

There is good suggestion for the laser system, which, it seems, can be build now.

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